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INCREMENTAL TRANSFER EFFECTIVENESS

Stanley N. Roscoe

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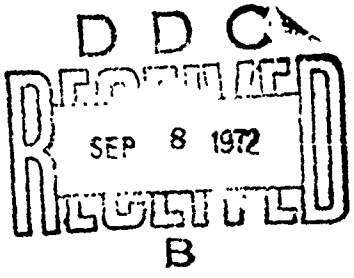

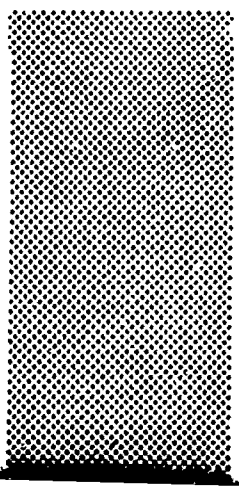

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A new method of measuring transfer of learning is presented. A universal relationship is postulated in which the effectiveness of successive increments of training on one task, as measured by the relative incremental savings in learning a second task, is a negatively decelerated function of the time devoted to pre-training or interpolated training on the former task. It is further postulated that the relationship, inferred from aircraft pilot training situations, applies in different forms to all educational experiences, thereby allowing all formal educational programs, in theory, to be evaluated in terms of their incremental cost effectiveness.

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INCREMENTAL TRANSFER EFFECTIVENESS

Stanley N. Roscoe
University of Illinois

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III

FOREWORD

This report represents the theoretical basis for a research project currently being conducted at the Aviation Research Laboratory of the Institute of Aviation, University of Illinois. The research was supported initially by the Link Foundation. It is currently supported by the Air Force Office of Scientific Research under contract F44620-70-C-0105 with the University of Illinois.

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BACKGROUND

Traditional measurement of transfer of training deals with the degree to which learning one task is facilitated by the prior or interpolated learning of another. For this measurement, two groups are required. Speed of learning by an experimental group, previously trained on another, usually similar, task is compared with that of a control group having no special previous training.

Consider, for example, the hypothetical findings, summarized in Table 1, in which the transfer from prior study by two experimental groups is evaluated in terms of the relative amounts of tutoring required to pass the same examination.

TABLE 1
Hypothetical Transfer Data

Student Group	Hours of Prior Study of German	Hours of Tutoring Required to Pass
Experimental A	500	100
Experimental B	100	100
Control	None	200

One group of students devoted an average of 500 hours each to the study of literary German during two years of classwork; a comparable group devoted an average of 100 hours to the study of The key to rapid translation of German by C. V. Pollard. Thereupon, members of both groups required an average of 100 hours of individual tutoring to reach criterion performance in translating scientific

German. Members of a control group, with no prior study of German, required an average of 200 hours of tutoring to meet the same criterion.

Which of the first two groups demonstrated the higher transfer of learning? Clearly the answer based on our traditional measure, percent transfer, does not adequately describe the relative performances of our two hypothetical experimental groups. Nevertheless, since the days of Weber, Fechner, and Volkmann (see Woodworth, 1938) investigators of transfer have failed to take proper quantitative account of the amount of prior or interpolated practice contributing to the observed transfer effects.

The basic precent transfer computation is

$$\frac{Y_c - Y_x}{Y_c}, \qquad (1)$$

wl. .

Y_c = time, trials, or errors required by a control group to reach a performance criterion;

Y_x = corresponding value for an experimental, or transfer, group having received prior practice on another task.

Substituting values from Table 1,

$$\frac{200 - 100}{200} = \frac{1}{2} = 50\%.$$

Each of the two transfer groups in our hypothetical example demonstrated 50 percent transfer, despite the fact that one invested five hours for every hour invested by the other on prior practice. If time has any value, a meaningful basis for the measurement of transfer effectiveness in terms of its cost is essential.

THE NOTION OF INCREMENTAL TRANSFER

The effectiveness of practice on one task, as reflected in a saving in time

to learn a second criterion task, is recognized to be a function of the similarity between tasks, the recency of prior practice, and in the case of interpolated as opposed to prior practice on the initial task, the distribution of such practice. For reasons beyond comprehension, there has been no recognition in the psychology of learning of the intuitively obvious fact that the effectiveness of transfer is also a negatively decelerated function of the amount of such practice.

Supporting Evidence

Investigators performing experiments in closely related research contexts have brushed against the phenomenon and have noted the relationship but typically have not followed up with systematic scientific inquiry. For example, at the University of Iowa in the early 1950s, Lewis, McAllister, and Adams (1951) and McAllister and Lewis (1951) studied facilitation and interference in psychomotor performance on a manual tracking task as functions of the amounts of prior and interpolated practice on the same basic task with control-display relationships reversed. They found clear evidence of a relationship between amount of practice on one task and its effect upon subsequent performance on the other under certain circumstances, but the relationships were less clear in others. Lewis, McAllister, and Adams asserted (p. 247): "There have been no previous investigations of facilitation and interference in motor learning which have any direct bearing on the problem." Furthermore, no subsequent investigation has been found that bears directly on it.

An earlier report from the field of verbal learning also suggests the negatively decelerated nature of transfer effectiveness for successive increments of training. McGoech (1929) found a negatively decelerated relationship between resistance to retroactive interference from a fixed amount of interpolated practice on one list of nonsense syllables and the amount of prior practice on the criterion list. McGoech states (p. 258): "The conclusion is clear that, measured in terms of saving score, retroactive inhibition [interference] varies inversely as the number of presentations given the material to be learned. The curve of inhibition

plotted against number of learning repetitions shows marked negative acceleration [sic; the curve as shown is negatively decelerated]."

The investigation of this subject was extended systematically by Briggs (1957) to include various amounts of interpolated as well as original learning. Briggs confirmed the negatively decelerated relationship McGoech had observed between amount of original learning and resistance to retroaction and, in addition, found that the strength of retroactive interference bears a negatively accelerated relationship to the amount of interpolated learning.

Unfortunately, the unrecorded performance data for interpolated learning trials, which were incidental to Briggs' experiment, were lost during his move from Northwestern to Ohio State. In any case, it would not have been possible to determine the transfer effectiveness of successive increments of original learning upon interpolated learning, because Briggs' experimental design did not include a group receiving no original learning trials as would have been needed if his object had been to investigate transfer effectiveness.

Hypothetical Relationships

Now consider another set of hypothetical data presented numerically in Table 2 and graphically in Figure 1. The numbers presented, although hypothetical, are not entirely imaginary. Previous studies of flight training spread over 21 years at the University of Illinois (Williams and Flexman, 1949; Williams and Adelson, 1954; Muckler, Nygaard, O'Kelly, and Williams, 1959; Povenmire and Roscoe, 1970) provide fragmentary but directly related evidence supporting the shape of the hypothetical functions presented in Figure 1, if not the specific values.

There is evidence, for example, that the first hour of instruction in a ground trainer can save more than one hour in pre-solo flight training. The fifteenth hour in a ground trainer surely would not; its contribution would be difficult to measure. There is convincing inferential evidence that successive pre-solo hours in a ground trainer yield decreasing increments of saving in pre-solo flight time, and the same decreasing incremental benefits would be expected for any successively related educational experience.

TABLE 2

Hypothetical Data upon Which Curves Shown in Figure 1 Are Based

	GROUND TRAINER HOURS, X															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Flight Hours, Y	10.00	8.60	7.44	6.48	5.68	5.01	4.45	3.98	3.59	3.27	3.01	2.81	2.66	2.56	2.51	2.50
Flight Hours Saved, $Y_o - Y_x$		1.40	2.56	3.52	4.32	4.99	5.55	6.02	6.41	6.73	6.99	7.19	7.34	7.44	7.49	7.50
Percent Transfer, $\frac{Y_o - Y_x}{Y_o} \cdot 100$		14.0	25.6	35.2	43.2	49.9	55.5	60.2	64.1	67.3	69.9	71.9	73.4	74.4	74.9	75.0
Incremental TER, $\frac{Y_{x-\Delta x} - Y_x}{\Delta X}$		1.40	1.16	0.96	0.80	0.67	0.56	0.47	0.39	0.32	0.26	0.20	0.15	0.10	0.05	0.01
Cumulative TER, $\frac{Y_o - Y_x}{X}$		1.40	1.28	1.17	1.08	1.00	0.93	0.86	0.80	0.75	0.70	0.65	0.61	0.57	0.53	0.50

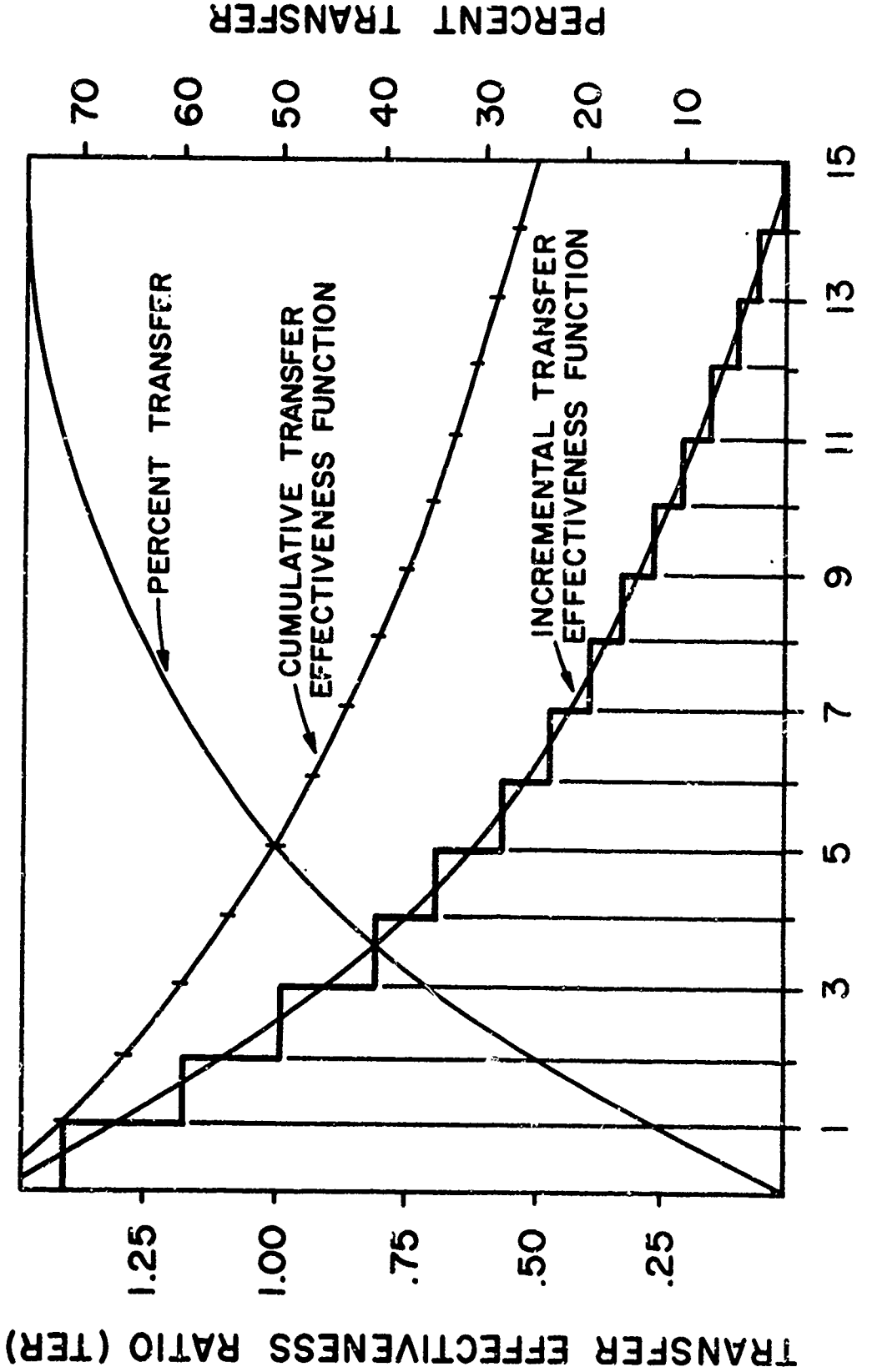

Figure 1. Relationships among transfer measures based on hypothetical data for general aviation ground trainers used in a ten-hour flight curriculum.

TRANSFER EFFECTIVENESS FUNCTIONS

The curve that results when the incremental relative savings in learning a criterion task are plotted for successive increments of pretraining or interpolated training on another task is termed the Incremental Transfer Effectiveness Function (ITEF). When the ratios of total savings on the criterion task to total time spent on the prior or interpolated task are plotted, the resulting curve is the Cumulative Transfer Effectiveness Function (CTEF). As shown in Figure 1, both curves are postulated as being negatively decelerated and, therefore, inversely related to the negatively accelerated curve in Figure 1 which expresses conventional percent transfer as a function of amount of training on the prior task.

$$CTEF = \frac{Y_o - Y_x}{X}, \tag{2}$$

where

$Y_o = Y_c$ of Equation (1);

Y_x = same as Equation (1);

X = total time, trials, or errors required by the experimental group to reach a performance criterion.

$$ITEF = \frac{Y_{x-\Delta x} - Y_x}{\Delta X}, \tag{3}$$

where

ΔX = incremental unit in time, trials, or errors;

Y_x = same as Equations (1) and (2);

$Y_{x-\Delta x}$ = amount of time, trials, or errors required by experimental group to reach a performance criterion after $x-\Delta x$ training units.

It is frequently interesting and occasionally instructive to attempt a reinterpretation of old data in terms of new concepts. By estimating the values of appropriate points on some of the learning curves presented by Lewis, McAllister, and Adams (1951: Fig. 2, p. 250; Fig. 7, p. 257) it is possible, with a straight-edge and a little imagination, to extract the set of approximations for trials to criterion and trials saved on a transfer task as a function of the amount of original learning on a related task as shown in Table 3. By calculating the resulting values for percent transfer and transfer effectiveness shown in Table 3 and by plotting them as shown in Figure 2, we observe a set of relationships, based on real data, having the same general form as the hypothetical curves in Figure 1. Caution is in order, however, because other less orderly data from the same series of experiments do not offer similar comfort for the incremental transfer hypothesis.

TABLE 3

Reinterpretation of Data Extracted from Graphically Presented Results of Lewis, McAllister, and Adams (1951)

	Number of Learning Trials on Original Task			
	0	10	30	50
Trials to Criterion of Transfer Task	13.5	10.0	7.0	5.0
Trials Saved on Transfer Task		3.5	6.5	8.5
Percent Transfer		28	52	68
Cumulative Transfer Effectiveness Ratio		0.35	0.22	0.17
Incremental Transfer Effectiveness Ratio		0.35	0.15	0.10

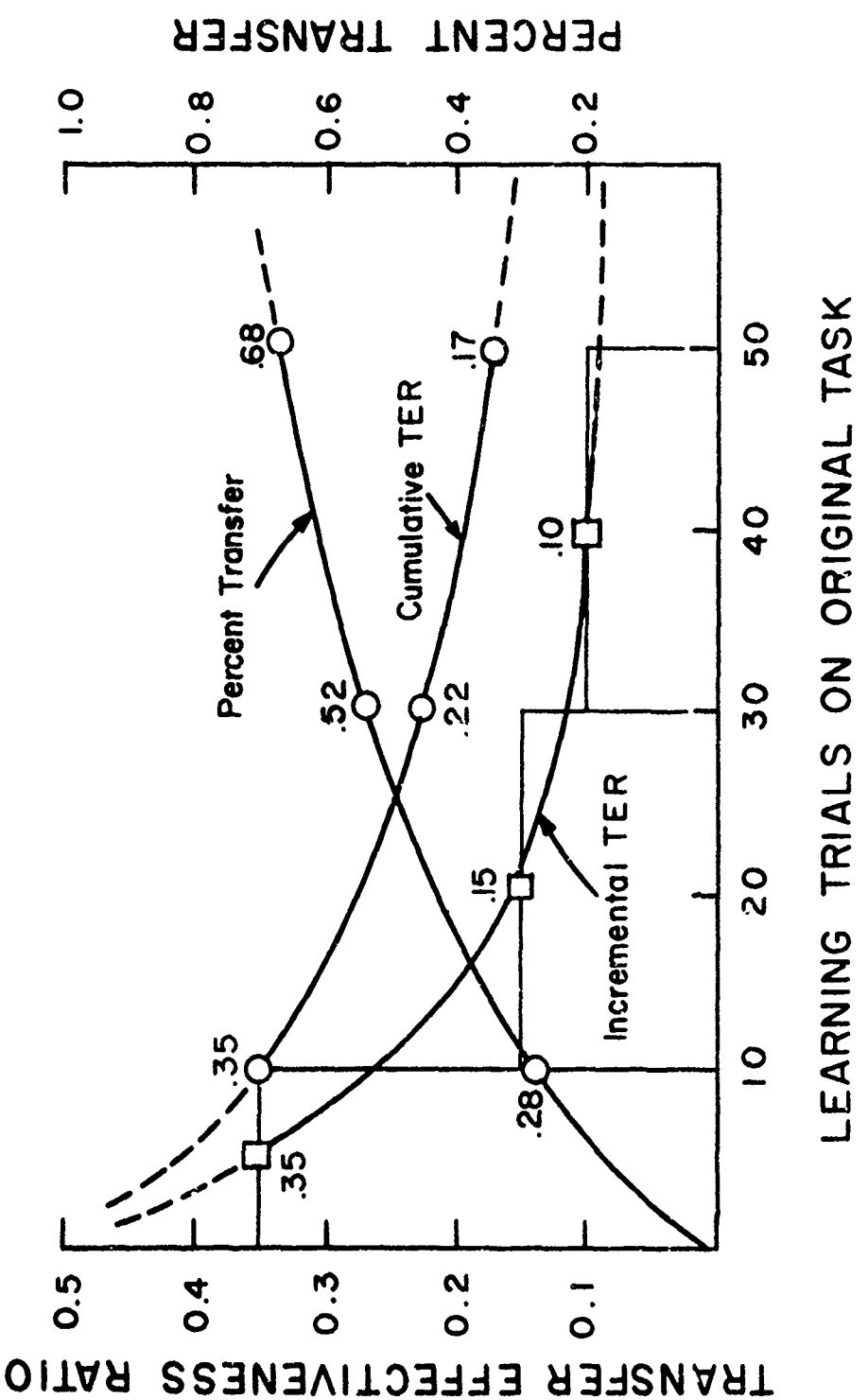

Figure 2. *Graphic presentation of percent transfer, cumulative transfer effectiveness, and incremental transfer effectiveness functions for Lewis, McAllister, and Adams data shown in Table 3.*

INCREMENTAL COST EFFECTIVENESS

Despite the fact that the evidently decreasing transfer from successive increments of any pretraining has been overlooked by experimental psychologists and educators, the importance of the relative amounts of time invested in various training activities is evident when respective costs per unit are considered. If the cost of instruction in a training airplane is $18.00 per hour and the corresponding figure for ground training is $6.00 per hour, a flight student could save money by buying ground-trainer time until his benefit from an additional hour would be less than he would gain from one-third of an hour of dual instruction in the airplane.

The legal substitution of 11 hours of ground-trainer time for 11 hours of flight time in the private pilot curriculum by certain schools approved by the Federal Aviation Administration was arrived at on the basis of empirical experience rather than formal experimentation. Nevertheless, the law represents the implicit recognition by the FAA that the cumulative transfer effectiveness function for modern general aviation ground trainers applied to the routine training of private pilots drops below unity at about the eleventh hour. The validity of this legally established value gained support from a recent experimental study (Povenmire and Roscoe, 1971) in which the saving in flight time in the private pilot curriculum equaled the 11 hours spent in a modern ground trainer. However, 11 hours in an older model resulted in a saving of nine hours in the air.

The observation that the cumulative transfer effectiveness function for a particular ground trainer in a particular flight curriculum drops below unity at the eleventh hour does not guarantee that the use of the ground trainer is economically justified to that point. Whether or not that is the case depends upon the incremental transfer effectiveness of the eleventh hour and the ratio of costs of an hour in the ground trainer to an hour in the aircraft. The ground trainer might still be yielding significant transfer at this point, but the incremental transfer effectiveness might not be sufficient to be cost effective.

Nevertheless, the fact that the incremental transfer effectiveness ratio has

dropped below the cost ratio and has become relatively inefficient does not necessarily indicate that further use of a ground trainer by a given student should be stopped. Many considerations, such as aircraft availability, weather, local traffic congestion, safety, or a requirement to complete a training phase by a given date, may make it advantageous to continue use of a ground trainer beyond the cost-effectiveness crossover.

TRAINING STRATEGY

Incremental transfer effectiveness to this point has been considered as a simple function of time; this is clearly an oversimplification. The effectiveness of any training device or training curriculum depends upon how it is used; it is influenced by all the well known facts concerning conditions favorable and unfavorable to learning. Naturally, transfer effectiveness functions will change accordingly, and for this reason the incremental transfer effectiveness measure may prove to be a highly sensitive experimental tool for studying learning phenomena and for optimizing training strategies.

In this context, it is evident that the same training device may exhibit different transfer effectiveness functions for different phases of a multiphase curriculum. Although a general aviation ground trainer may have reached a point of relative ineffectiveness for pre-solo training, the same trainer would be expected to exhibit renewed effectiveness for instrument and cross-country training phases. Thus, the incremental transfer effectiveness function for any particular training device may be expected to be a series of negatively decelerated curves associated with successive phases or blocks of a training curriculum. The shape and steepness of the curves may be expected to vary accordingly, and the point at which each drops below the cost-effectiveness cutoff line will help determine the training strategy that will yield the most effective distribution of practice on the various curriculum phases or learning blocks.

GENERALITY OF APPLICATION

Research findings are basic to the extent that they are generalizable to a broad spectrum of applications. It is postulated that the negatively decelerated nature of incremental transfer effectiveness applies to the relationships among all learning experiences, whether they exhibit positive or negative transfer, and it is predicted that future research will support this generalization.

The most useful single measure for the educational strategist is the cost effectiveness of any educational experience. In aviation training, time spent in ground trainers must be justified in terms of savings in flight time in corresponding airplanes; time spent in small simple airplanes must be justified in terms of relative savings in large complex aircraft.

In public education, the curricular strategy must take into account the cost effectiveness of each phase of training in terms of relative savings in successively higher and more expensive phases. For each individual, the decision to terminate formal education is based on his estimate of the diminishing incremental benefits to him of each successive unit of educational time or money.

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